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National Institute of Information and Communications Technology
Furukawa Electric Co., Ltd.

Press Release

Successful High-Capacity Transmission Over Multi-core Fiber Link Amplified with 19-core Optical Amplifier

- Towards practical realization of space-division multiplexing technology employing component integration, reduced energy consumption and record transmission capacity -

【Points】

- Development of batch 19-core optical amplifier in each of C and L band
- 715 Tb/s transmission of 345 wavelength channels with PDM-16QAM modulation over 2,009 km
- Record throughput-distance product for link using SDM amplifier and largest data transmission of any long-haul transmission demonstration

The National Institute of Information and Communications Technology (NICT, President: Hideyuki Tokuda, Ph.D.) and Furukawa Electric Co., Ltd. (Furukawa Electric, President: Keiichi Kobayashi) jointly report a record SDM transmission experiment using multi-core fiber amplifier. Furukawa Electric developed a 19-core Erbium-doped-fiber amplifier utilizing cladding-pumping technology in order to share electrical power between the large number of spatial channels. The amplifier was then integrated into NICT's state of the art transmission test bed of for a record transmission demonstration. Fully decoded optical data transmission of 715 Tb/s was achieved over a distance of 2,009 km using coded polarization division multiplexed (PDM) -16 quadrature-amplitude modulation (QAM) of 345 carriers over the C and L band in a re-circulating transmission loop.

Previously, short-distance, high-capacity transmission in high-core count EDFAs and long-distance transmission in a C-band 7-core amplifier was achieved. This demonstration showed high-core count cladding pumped EDFAs are suitable for high throughput transmission over 1,000s km in both C and L band.

The results of this demonstration(1) were selected for presentation as a post-deadline paper at the 2019 Optical Fiber Conference (OFC 2019), the world's largest event for optical communications research.

【Background】

Single mode, multi-core fibers (MCFs), multi-mode fiber, or a combination of both have been used in numerous high-capacity and long distance SDM transmission demonstrations(2). However, SDM technologies are also driven by the need for hardware integration and energy savings. As such, the successful development of SDM amplifiers is crucial for commercial realization of SDM technologies. In particular, large core-count cladding pumped multi-core erbium doped fiber amplifiers (MC-EDFAs) offer potential to integrate hardware(3) and significantly reduce the number of pump lasers respective to the number of spatial channels(4). Furthermore, such amplifiers are not only compatible with equivalent MCFs, but may also amplify several lower core-count MCFs, arrays of single-mode fibers or even signals from few-mode fibers. Previously large capacity was reached over short distances in a high-core count EDFA(5) and long distance transmission was achieved using a C-band 7-core amplifier(6). This demonstration showed high-core count cladding pumped EDFAs are suitable for high throughput transmission over 1,000s km in both C and L band, achieving the highest throughput-distance product of any SDM amplifier experiment of 1.44 Exb/s x km.

【Achievements】

The partners have performed a record data-throughput x distance experiment using an SDM amplifier. NICT constructed a recirculating transmission test-bed around the 19-core, cladding-pumped EDFA developed by Furukawa Electric. Fig.1 shows a comparison with a selection of existing transmission demonstrations using SDM amplifiers.

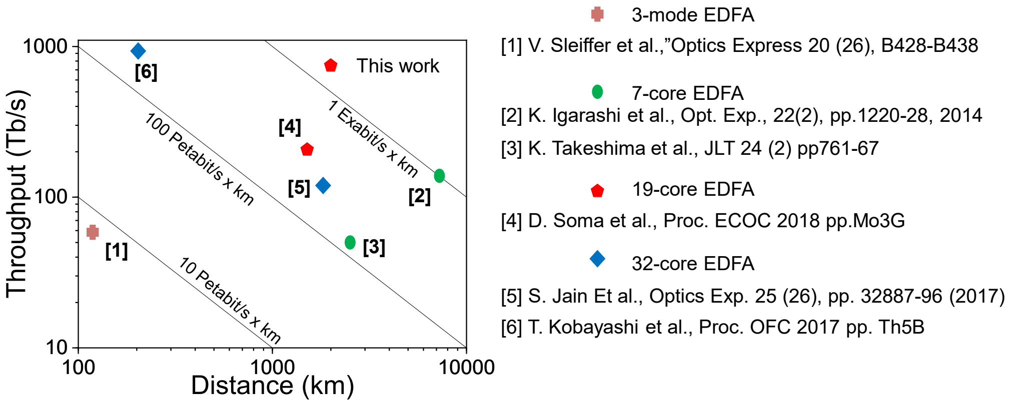

Fig.1: Comparison between our 4-core, 3-mode optical fiber and other optical fibers

The transmission system is made up from the following four main technologies.

- 19-core cladding pumped EDFA for C + L band transmission
- 19-core multi-core fiber and recirculating transmission set-up
- An optical frequency comb light source generating 345 wavelength channels
- PDM 16-QAM multi-level transmitter with 4 bit of data per symbol per wavelength

The amplifier, shown schematically in Fig. 2, was used to amplify signals in 19 cores simultaneously using two un-cooled multi-mode laser pumps per band. The combined pump power was 13.7 W and 43.5 W for the L-band and C-band EDFs respectively, equivalent to conversion efficiencies from electrical power of 40.3 % and 41.6 %.

【Future Prospects】

We are promoting R&D of innovative technology that achieves the early adoption of international standardization by industry-academia collaboration for establishing next-generation optical communication infrastructure technologies which can smoothly accommodate traffic for big data and 5G services. The results of this work were presented as a post deadline at the 2019 Optical Fiber Conference (OFC 2019), held in San Diego, USA from 3 to 7 March 2019.

【References】

(1) Ben Puttnam, Georg Rademacher, Ruben Luis, Tobias Eriksson, Werner Klaus, Yoshinari Awaji, Naoya Wada, Koichi Maeda, Shigehiro Takasaka and Ryuichi Sugizaki, ‘0.715 Pb/s Transmission over 2,009.6 km in 19-core cladding pumped EDFA amplified MCF link’ In Proc. Optical Fiber Conference (OFC) 2019 paper Th4B.1

(2) T. Mizuno et al. “Dense Space Division Multiplexed Transmission Over Multicore and Multimode Fiber for Long-haul Transport Systems,” J. Light. Technol. 34(6), pp. 1484-93, 2016

(3) J. Sakaguchi et al., “19-core MCF transmission system using EDFA with shared core pumping coupled in free-space optics” Opt. Exp., 22 (1), pp. 90-95, 2014

(4) S. Takasaka et al., “Increase of Cladding Pump Power Efficiency by a 19-Core Erbium Doped Fiber Amplifier,” In Proc. ECOC’17 pp TH.2.D

(5) T. Kobayashi et al., “1-Pb/s (32 SDM/46 WDM/768 Gb/s) C-band Dense SDM Transmission over 205.6-km of Single-mode Heterogeneous Multi-core Fiber using 96-Gbaud PDM-16QAM Channels,” In Proc. OFC’17 pp. Th5B

(6) K. Igarashi et al., “Super-Nyquist-WDM transmission over 7,326-km seven-core fiber with capacity-distance product of 1.03 Exabit/s*km,” Opt. Exp., 22(2), pp. 1220-28, 2014

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Appendix

1. Transmission system constructed for demonstration

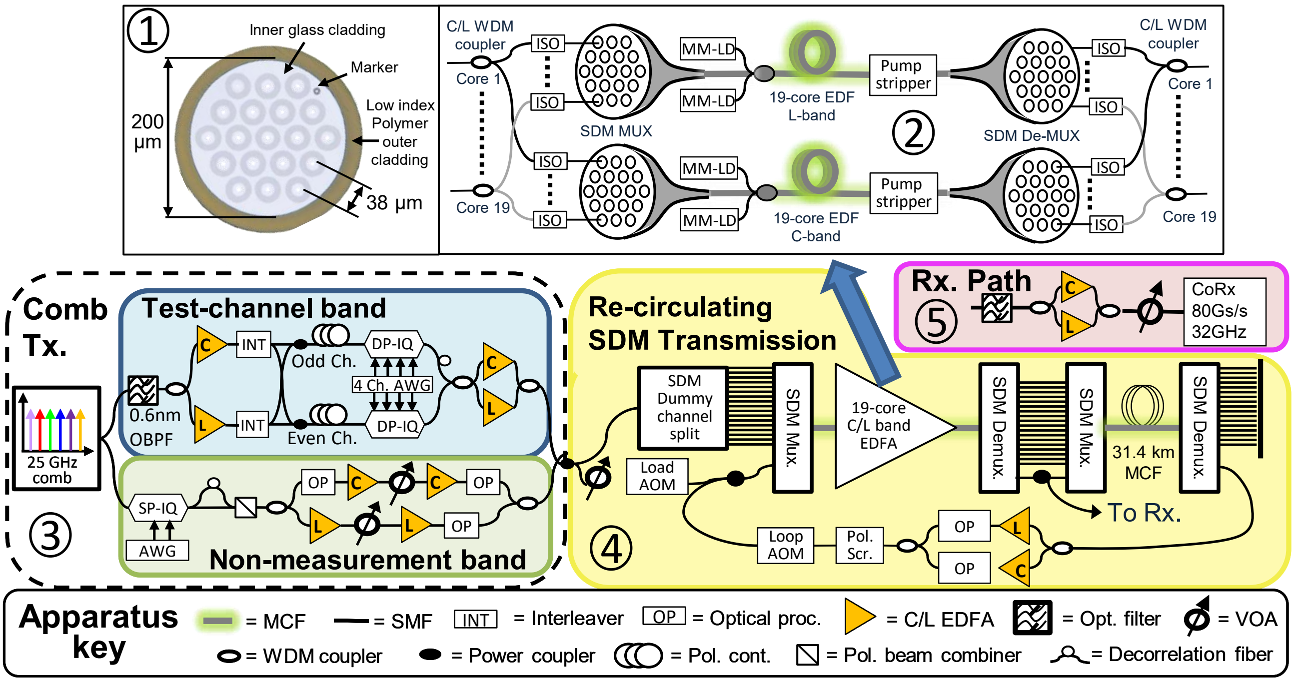

Fig.2: A schematic diagram of the 19-core EDFA and transmission system.

① Profile of the 19-core EDF with glass inner cladding and low-index polymer outer cladding

② Schematic of 19-core cladding-pumped EDFA for C and L-band transmission

③ Comb based transmitter used for generation of PDM 16-QAM modulation is performed on each wavelength contained in the output light of the optical comb light source. This output light is then split into 12 independent pseudo-random spatial signals by adding different optical delay differences

④ Re-circulating transmission set-up with amplification from 19-core EDFA

2. Results of Experiment

In the experimental system shown in Fig. 2, verification throughput and quality of the received channels was determined by 3 methods. In addition to the calculation of the bit-error-rate and Q-factor, the post-FEC performance of each spatial channel was computed by decoding corresponding received signal using LDPC codes from the DVB-S2 standard to achieve a specified BER and then assuming an additional hard-decision outer code. In addition the generalized mutual information (GMI) was calculated for each received channel and used to estimate the maximum possible throughput of each channel assuming the existence of the optimum error correcting code.

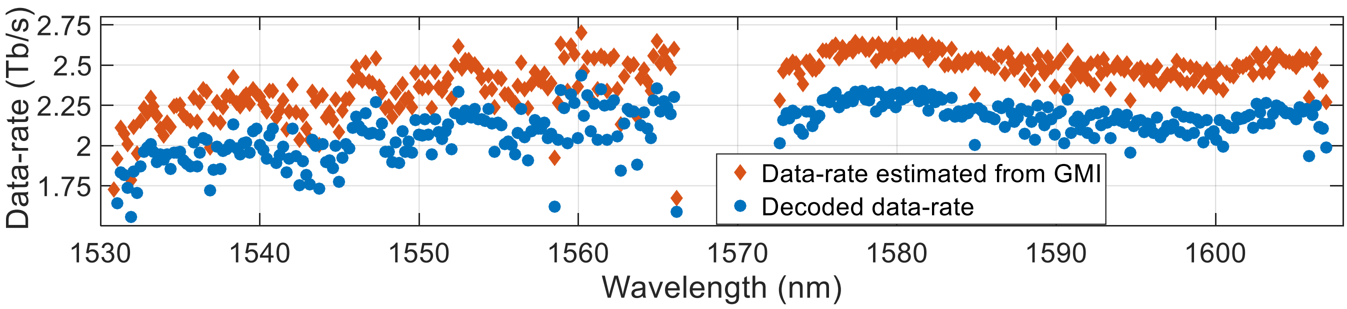

Fig.3: Comparison of modulation method

Fig. 3 shows the combined data-rate for each of the 345 wavelength channels in all 19-cores after decoding together with an estimate of the theoretical maximum data throughput estimated from the GMI.